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AD-A263 410

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

TECHNICAL NOTE 92-25

Canada

June 1992
Ottawa

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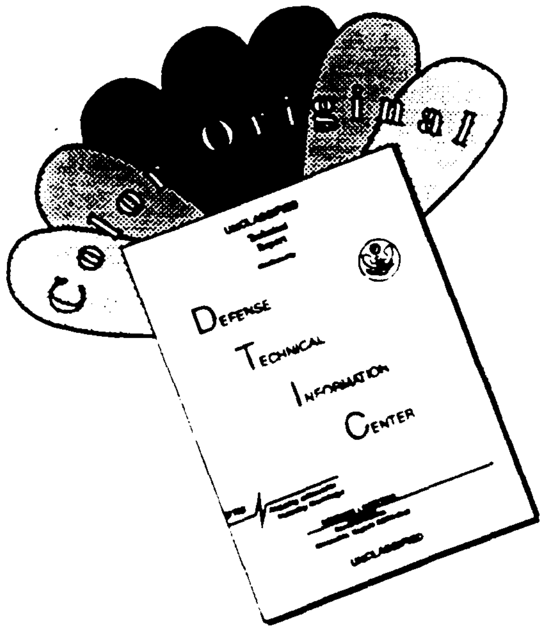

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Chemical Protection Section
Protective Sciences Division

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ABSTRACT

The Stereolithography (SLA) process was investigated to test its efficacy in producing three-dimensional parts from a Unigraphics CAD file. The method uses a photo-sensitive resin that is cured by means of a laser beam. The laser is directed to follow the CAD file and a model is built up with successive layers of resin between 0.127 and 0.508 mm (0.005 and 0.020 inch). Once the model is constructed, it is bathed in ultra-violet light for a post curing process. It was found that the model undergoes various amounts of contraction and expansion, distorting its shape. A quantitative assessment of this is given. The process is very useful in producing a three-dimensional model from the CAD file, but the dimensional integrity is not sufficient for producing accurately dimensioned prototypes.

RÉSUMÉ

Une enquête fut menée pour tester l'efficacité du processus de stéréolithographie (SLA) pour la production de pièces tri-dimensionnelles à partir d'un fichier CAO UNIGRAPHICS. La méthode utilise une résine photo-sensible qui est cuite au rayon laser. Le laser est dirigé pour suivre le fichier CAO et un modèle est construit avec des couches de résine de 0.127 millimétre à 0.508 millimétre (0.005 pouce à 0.020 pouce) d'épaisseur. Une fois le modèle construit, il est plongé dans un bain de rayons ultraviolets pour une deuxième cuisson. Il fut démontré que le modèle subit différentes contractions et expansions qui provoquent des distortions de sa forme. Une évaluation quantitive de ceci est fournie. Le processus est très utile pour la production de modèles tri-dimensionnels à partir d'un fichier CAO, mais la précision des dimensions n'est pas suffisamment grande pour la production de prototypes aux dimensions précises.

EXECUTIVE SUMMARY

The Stereolithography (SLA) process is a technique for generating three-dimensional prototypes from a CAD-file without using computer-numerical control (CNC) machining. A model of the object is constructed in the computer database. This part file is then the input data for the SLA process.

The SLA process uses a light-sensitive resin as the material for the model. The computer data are remodelled into successive layers approximately 0.020 inch- thick (0.508 mm) which are scanned by a laser beam. This hardens the resin that is exposed to the beam. The basic chemical component is acrylate ester of Bisphenol A-epoxy resin. After wash-off, the material is then post-cured in a bath of ultra-violet light.

The resin-model was compared to the computer-model dimensions over the critical variables. All finger lengths and diameters were specified along with the crotch lengths and the palm, hand and wrist diameters. It was found that there were non-uniform dimension changes resulting in uneven shrinkage. The layered structure of the prototype precludes its use as mould core without extensive surface finishing. There are also toxicity warnings for the uncured material.

The three-dimensional prototype that results from this process *can be very valuable for* demonstration purposes and for some design assessment, but it does not serve the purpose of an accurately-dimensioned form suitable for producing dimensionally accurate model gloves by means of the latex-dip method. However, the method is very useful for producing three-dimensional forms for assessment and comparison with other prototypes.

1.0 INTRODUCTION

At the Defence Research Establishment Ottawa, computer-aided design and manufacturing techniques are used for the production of prototype protective equipment for the Canadian Forces (CF). This includes gas masks, chemical warfare (CW) protective clothing, gloves, boots and much more. Extensive research is performed to ascertain the performance characteristics of materials that are used in the production of these items.

In order to assess the experimental forms of items, prototypes have to be made. The work described in this report examines the utility and efficiency of one subset of this process -- that of constructing a model from a CAD database by means of the process called stereolithography (SLA). This process extracts the information from a computer file containing a CAD model and uses this to direct a laser beam over a resin bath. The beam cures the resin layer by layer, and a model of the part in the computer file is produced. An analysis follows as to how well the model thus produced matches the design criteria in the computer file.

2.0 BACKGROUND

Producing prototypes can be a time-consuming and costly process. For our needs, the methods of computer-aided manufacturing offer a way of producing prototypes using computer numerical control (CNC) machines. Prototypes of gloves have been produced very effectively by this method (1). Here a computer model is built up and a three-axis CNC mill is programmed to cut the model directly from the data contained in the computer memory. These prototypes are usually made from aluminum since it is much softer than steel and consequently requires less time to cut and produces less wear and tear on the tools.

Further, prototypes made from metal may not be required. A three-dimensional model is often useful and highly informative, but it does not need to be in the material of the finished product. For demonstration purposes, a plastic may be quite satisfactory. This prototype was made with two objectives in mind: one, does the form produced by the SLA process maintain dimensional integrity when compared to the computer model and two, can the resin form be used for dip molding prototype gloves for preliminary dexterity tests?

3.0 THE COMPUTER-AIDED DESIGN AND MANUFACTURING SYSTEM

The CAD/CAM system consisted of Unigraphics software working from a MicroVAX II CPU. Unigraphics is a fully three-dimensional engineering design package capable of producing B-surface models,

solids, and programming for up to five axes on a wide variety of CNC machines, mills and controllers.

4.0 THE STEREOLITHOGRAPHY PROCESS

The GLOVE6.PRT was the starting point for the SLA process. A fully three-dimensional surfaced model was completed in Unigraphics. Views of this may be seen in Figures 1 and 2. The end surface of the model (at the forearm) was filled to complete the closed surface necessary for the input to SLA.

The computer model is used to direct a laser to cure successive layers of a resin so that a three-dimensional part can be built up. The resin begins as a liquid and layers of this are built up in increments of 0.005 to 0.020 inches (0.127 to 0.508 mm). After the part is formed the excess resin is drained off and fully removed with solvent rinse. The part is then 'post-cured' by exposure to ultra-violet light. During the post-curing there is some weight loss due to excess vapors being emitted but this amounts to less than 0.2% of the part weight. The major component of the vapors released is vinyl pyrrolidinone. More details concerning the chemical properties of the resin are contained in Appendix A.

5.0 DIMENSIONAL CHECKS ON THE MODEL

The form of the model may be seen in Figures 3 through 6. The SLA process constructed the part satisfactorily. The surface finish clearly showed the layer structure however, and the general roughness would require a sanding and polishing to be satisfactory for the dipping method of producing prototype gloves.

Some of the critical dimensions were measured on the computer model and then on the finished part. Because landmarks cannot be located with absolute certainty on the part, some degree of error is present here. Table 1 shows the comparisons between the computer model, the resin form and dipped gloves made from the form. In the table, the dimension names (D1, D2 through D5) denote the digits; D1 being the thumb, D2 the index finger through to D5, the little finger. C1 through C4 represent crotches beginning with the thumb/index finger crotch and extending to the ring finger/little finger crotch, C4. The tip taper refers to the distance on each digit between the tip of the digit and the taper ends and the uniform cross section part of the digit begins. The circumference set of dimensions refer to the circumferences at various points along the glove form. The "Max Palm", for instance, shows the circumference at the metacarpal crease in the palm and the "Max Forearm" shows the circumference around the largest part of the forearm of the glove form. Other dimensions of note include "WC- EOG" -- wrist crease to end-of-glove, that is, wrist crease to

Table 1: Dimensions of Computer Model and Resin Form

DIMENSION	CAD/CAM	NRC FORM	GLOVE
MAX Z THUMB	4.036	4.0	N/A
D1	4.978	5.8	5.3
D2	7.396	7.4	7.1
D3	8.412	8.3	7.95
D4	8.098	8.0	7.7
D5	6.295	6.3	6.0
HEIGHT FROM C1			
D2 (TIP)	12.116	12.4	11.7
C2	4.720	4.95	4.85
C3	4.338	4.75	4.85
C4	3.434	3.75	4.05
TIP TAPER			
D1	3.583	3.1	2.85
D2	2.063	2.15	2.1
D3	2.482	2.6	2.5
D4	1.903	1.9	1.95
D5	1.316	1.4	1.4
CIRCUMFERENCES			
MAX PALM	22.635	22.8	21.6
WRIST CREASE	21.001	20.95	20.2
MAX FOREARM	26.301	26.65	----
D1	7.980	8.1	7.8
D2	6.986	7.0	6.9
D3	7.137	7.3	7.0
D4	6.681	6.8	6.6
D5	5.943	6.0	5.9
MISC LENGTHS			
WC- EOG	17.473	17.3	----
D3 TIP- EOG	36.703	36.7	----
D3 TIP- WC	19.240	19.3	----

WC- EOG" -- wrist crease to end-of-glove, that is, .ist crease to the flat end of the form. "D3 TIP- F^G" is thu. the distance between the flat end of the glove and the longest finger tip.

A schematic of th' hand and its appropriate dimensions is shown in Figure 7. A detailed shape of the GLOVE6 design is shown in Figures 8 and 9 with a complete dimension set. The SLA model was made without the 101.6 mm (4.000 inch)-uniform extension to the arm.

Figure 10 shows the deviation from the design dimension at various points in the model. The arrows show the direction in which the SLA form deviated from the dimensions of the computer model. Some of the fingers were longer than expected while one was shorter. The finger crotches were further from the datum than required. The datum used here was the wrist crease.

The percentage deviations from the design criteria are shown in Table 2. The column "δ%" is calculated from the values of the variables in Table 1 by:

$$\frac{\text{NRC FORM - CAD FORM}}{\text{CAD FORM}} \times 100\%$$

So the δ values greater than zero mean that the resin model is larger than the CAD-determined dimensions, that is, there has been an expansion. As may be seen from these figures, some of the deviations were substantial (>5%) and all were distributed about the mean value.

The surface texture of the finished model displayed the layered structure of the laser scanning process, particularly at the ends of the fingers, and this was shown in Figure 6.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The stereolithography process produces a solid three-dimensional model from a Unigraphics part file. The result is extremely useful for examining the final shape of complex objects but it was found that the dimensional accuracy of the part was not sufficient for replicating models that required a low-tolerance fit to the original dimensions in the computer model. Further, the latex dipping process, used to manufacture test gloves for preliminary dexterity testing, leads to further shrinkage and dimensional distortion leading to a possible total distortion of +/-10%.

The SLA process is very useful for preparing mock-up style prototypes but not for prototypes that have to use the high temperatures and pressures of a rubber mould or require a high degree of dimensional accuracy.

Table 2: Deviation between Model and Form

DIMENSION	δ %
MAX Z THUMB	-0.9
D1	16.5
D2	-0.1
D3	-1.3
D4	-1.2
D5	-0.1
HEIGHT FROM C1	
D2 (TIP)	2.3
C2	4.9
C3	9.5
C4	9.2
TIP TAPER	
D1	-13.5
D2	4.2
D3	4.8
D4	-0.2
D5	6.4
CIRCUMFERENCES	
MAX PALM	0.7
WRIST CREASE	-0.2
MAX FOREARM	1.3
D1	1.5
D2	0.2
D3	2.3
D4	1.8
D5	1.0
MISC LENGTHS	
WC- EOG	-1.0
D3 TIP- EOG	0.0
D3 TIP- WC	0.3

7.0 REFERENCES

1. Hidson D.J., New Concepts in the Development of a CB Protective Glove Using CAD/CAM, Defence Research Establishment Ottawa, Report #1090, October 1991.

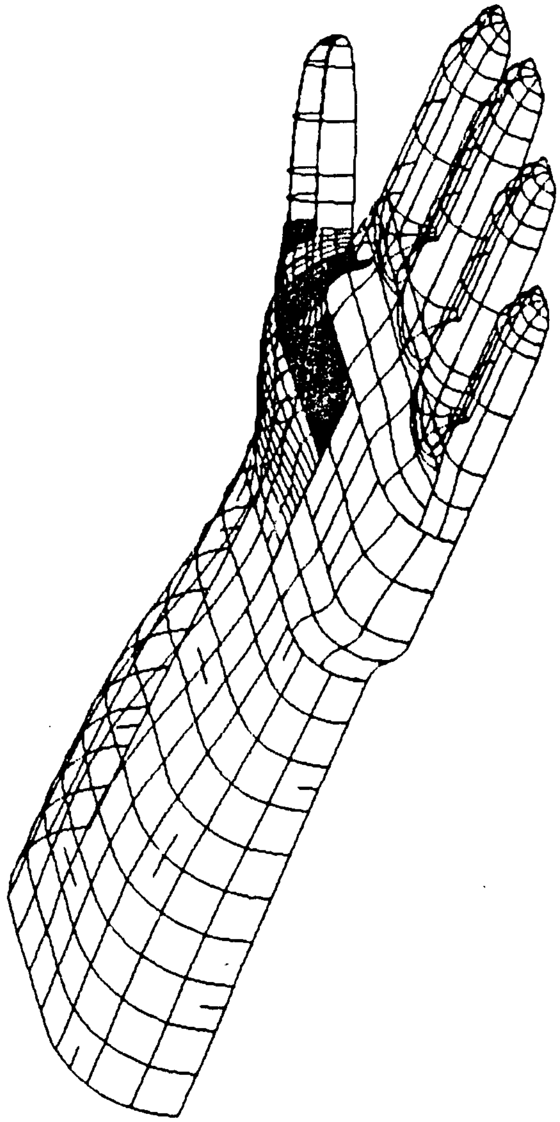

Figure 1: View of the Computer Model

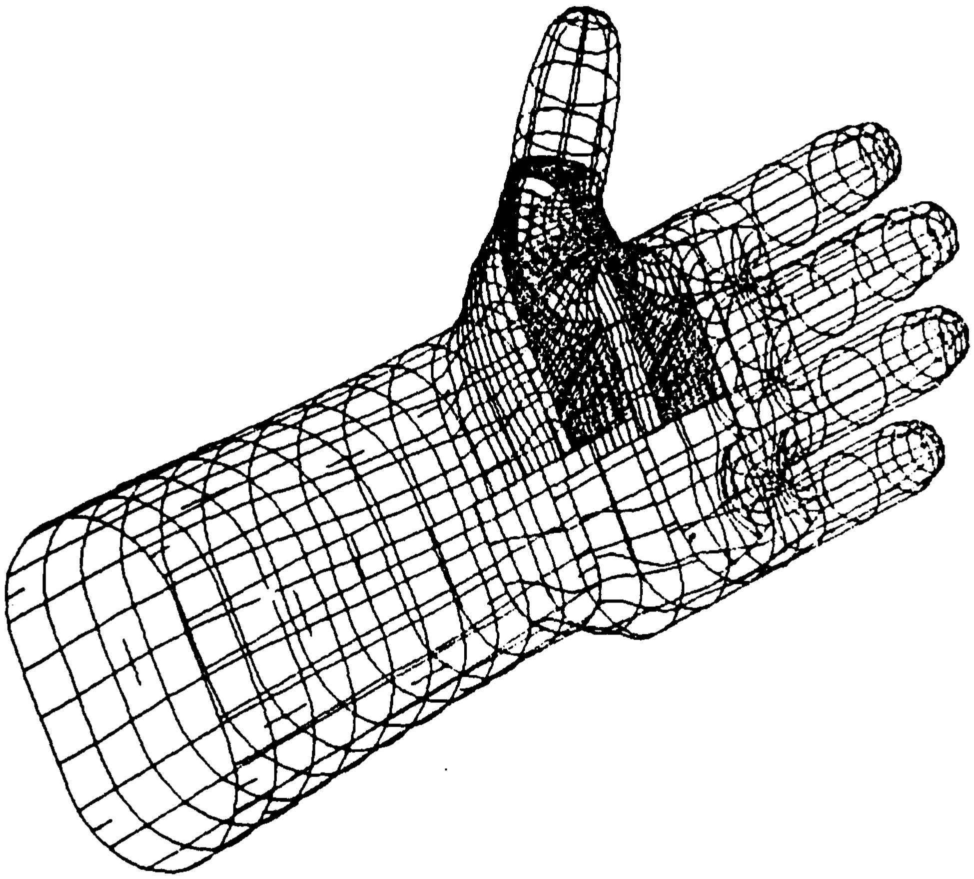

Figure 2: A Second View of the Computer Model

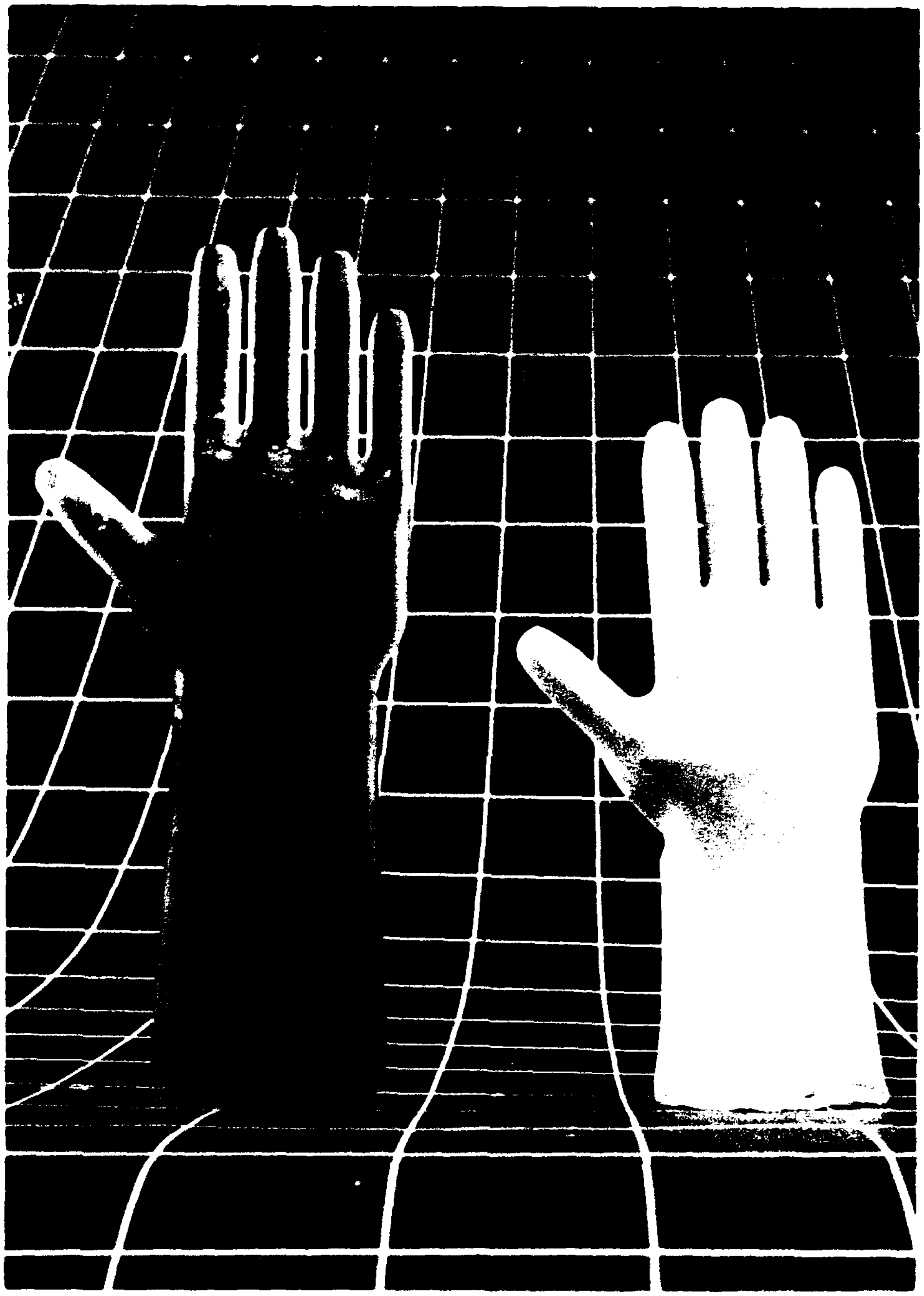

Figure 3: Top View of the Form

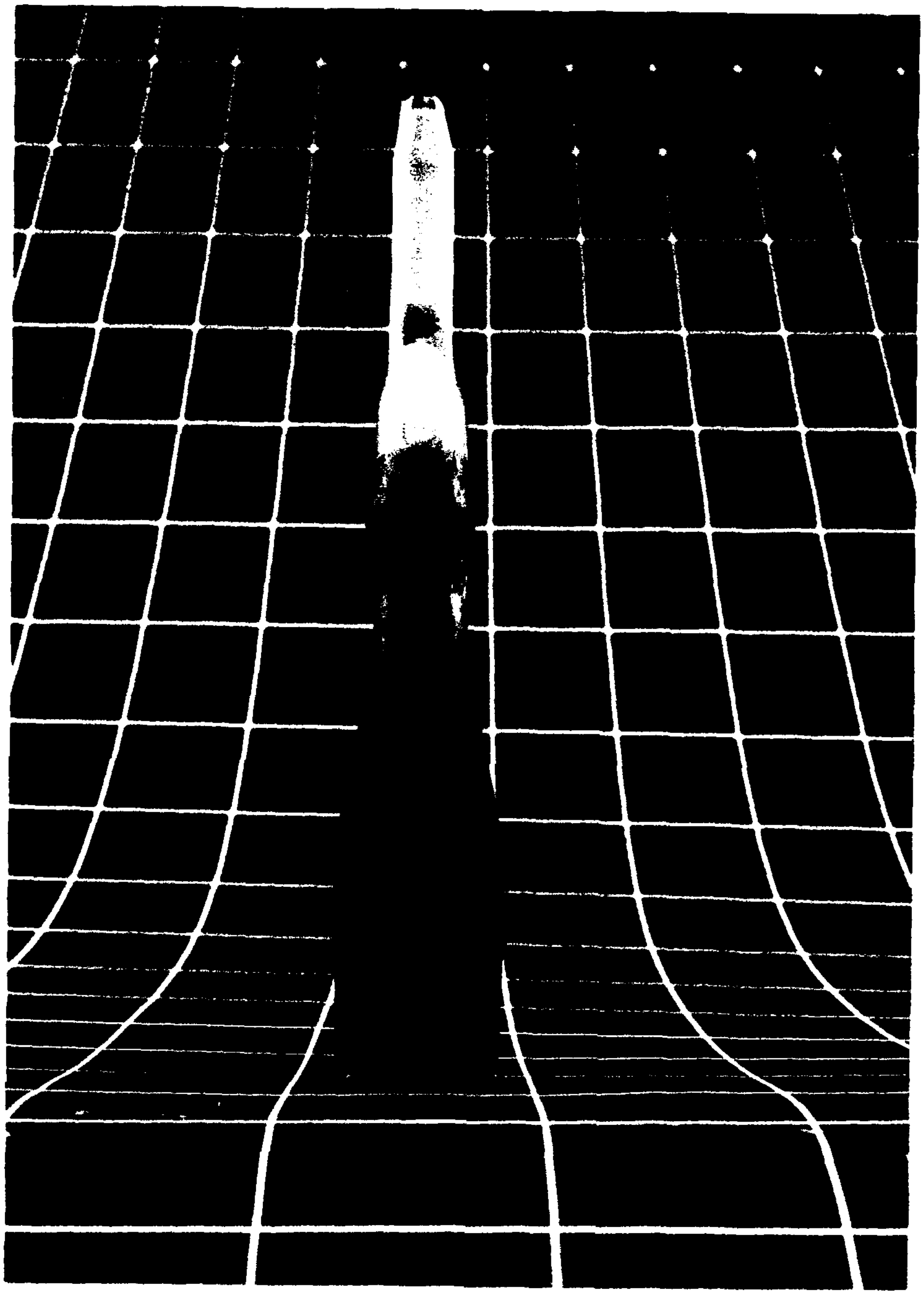

Figure 4: Side View of the Form

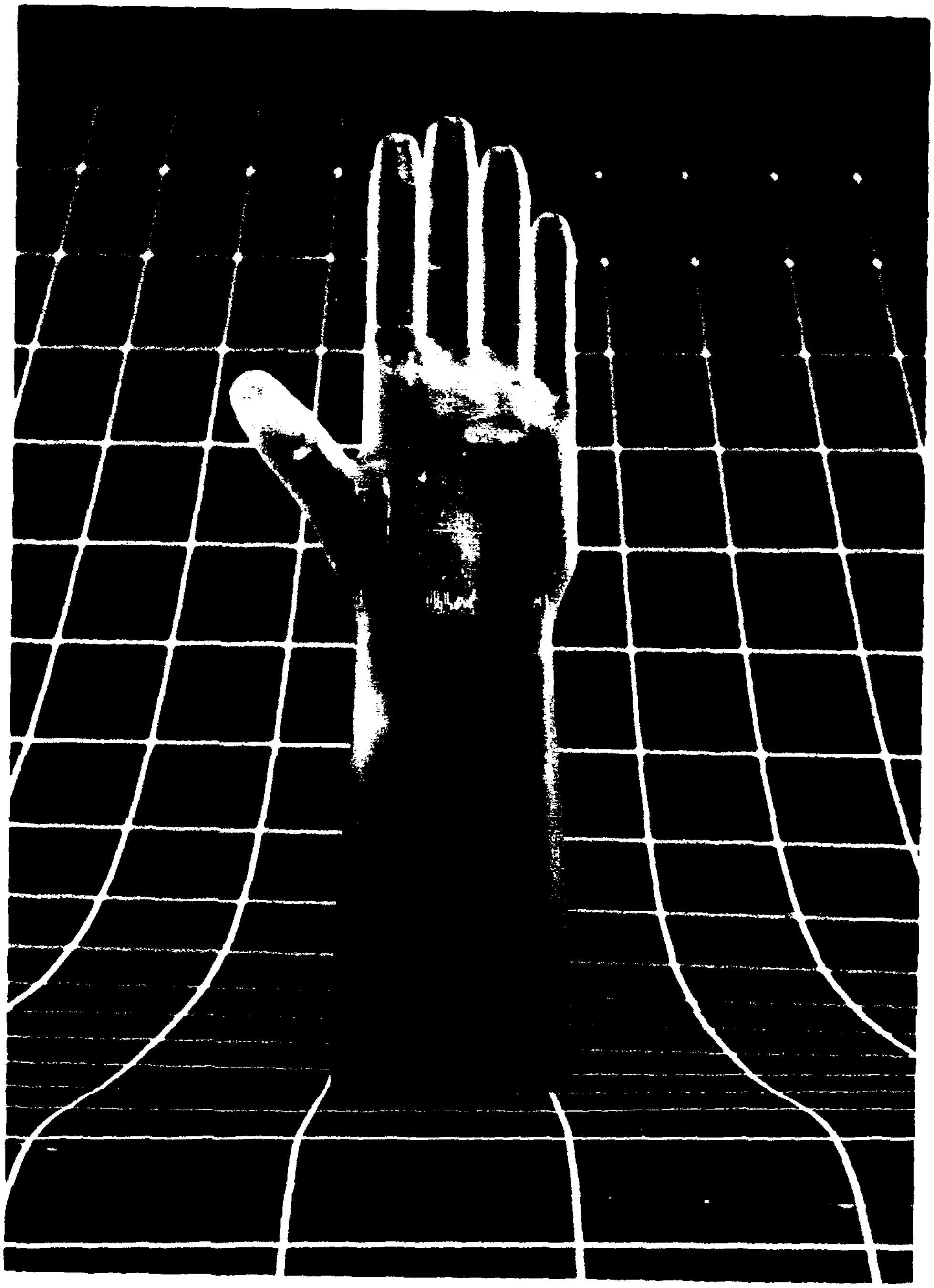

Figure 5: Isometric View of the Form

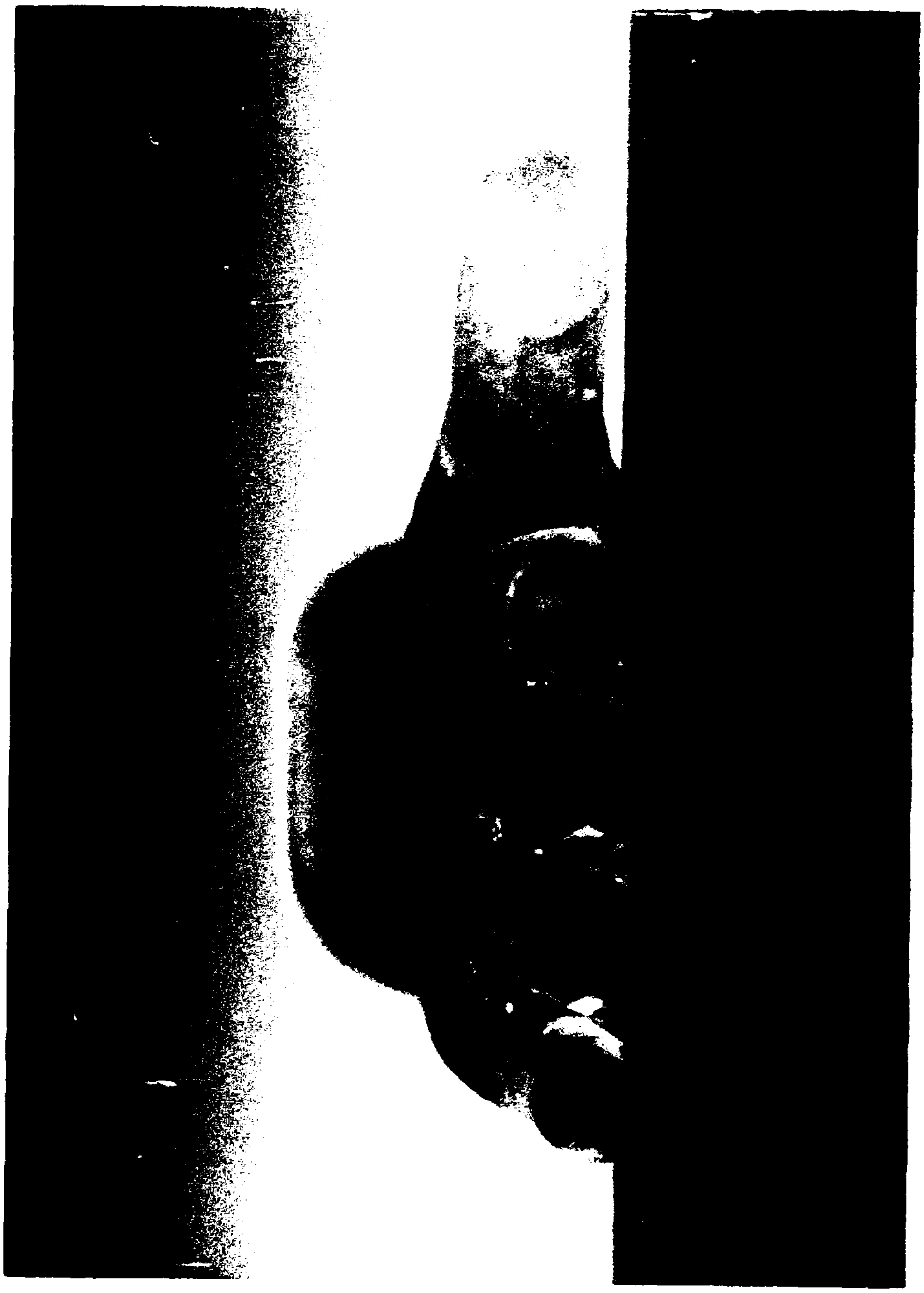

Figure 6: Close-up of Finger Tip

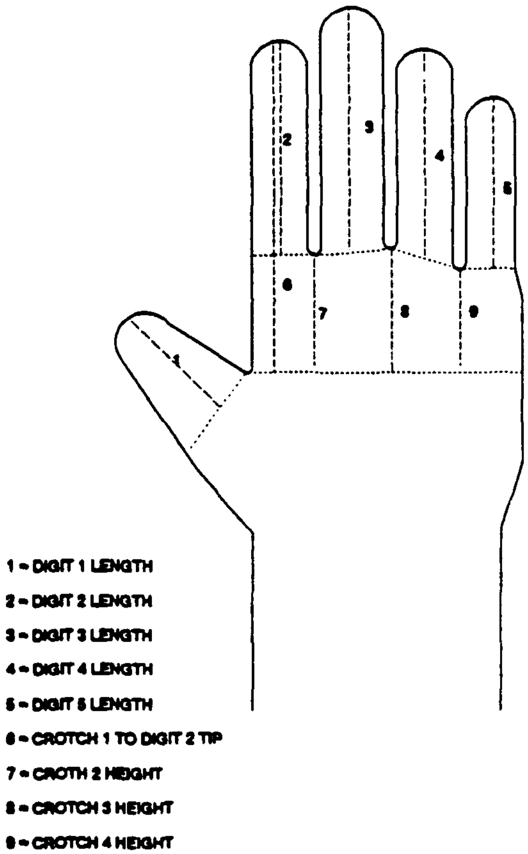

Figure 7: Schematic of the Hand and its appropriate dimensions

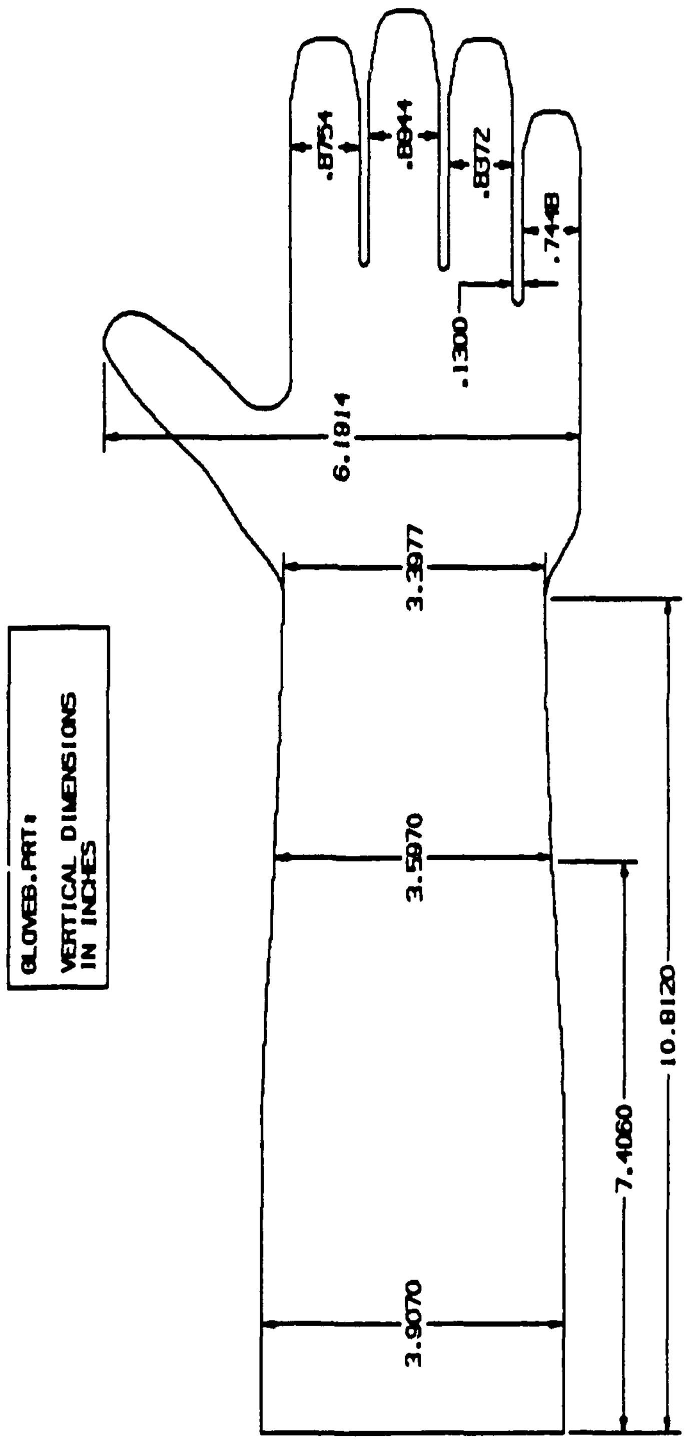

Figure 8: Dimension Set for the Form

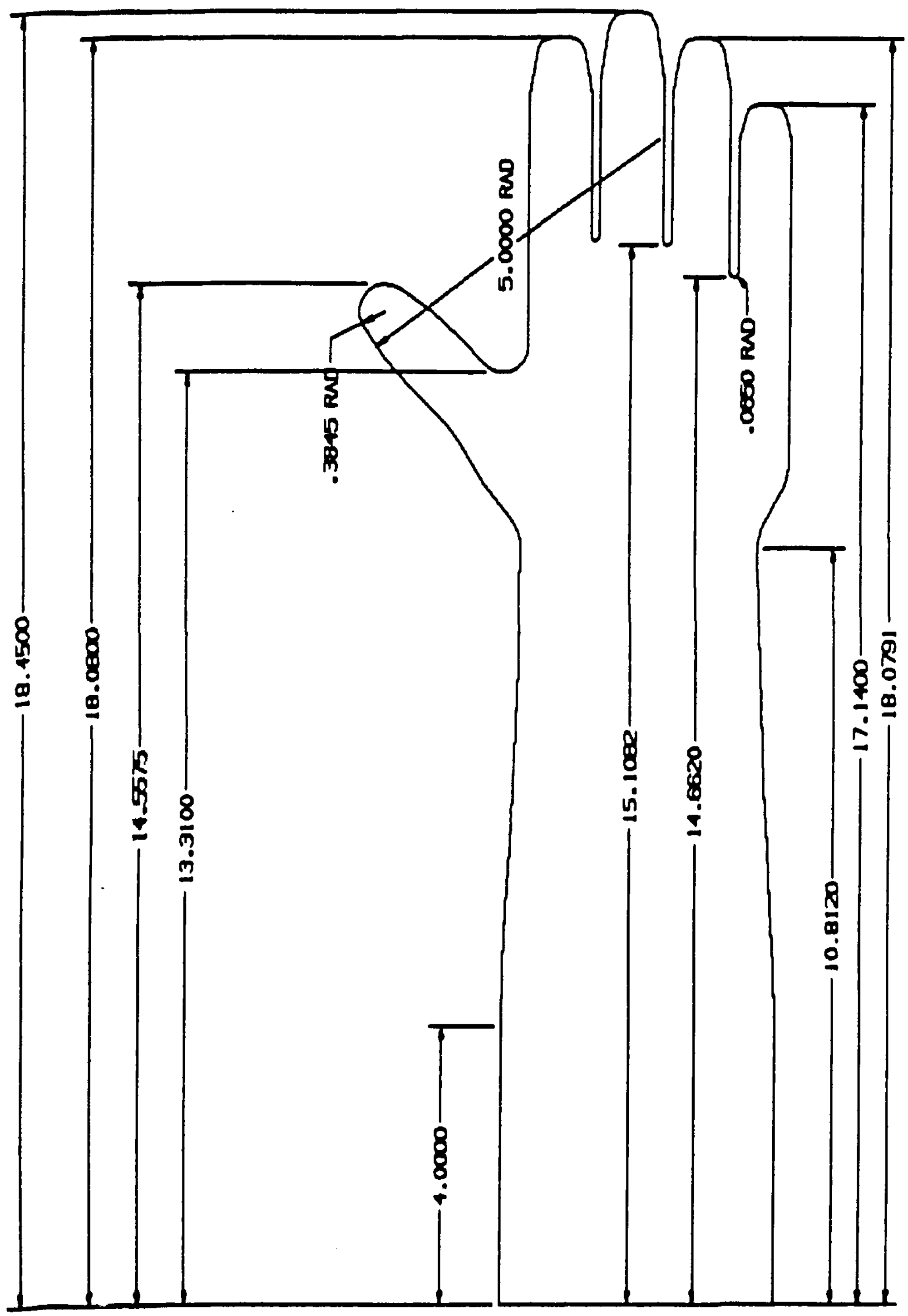

Figure 9: Dimension Set for the Form (cont'd)

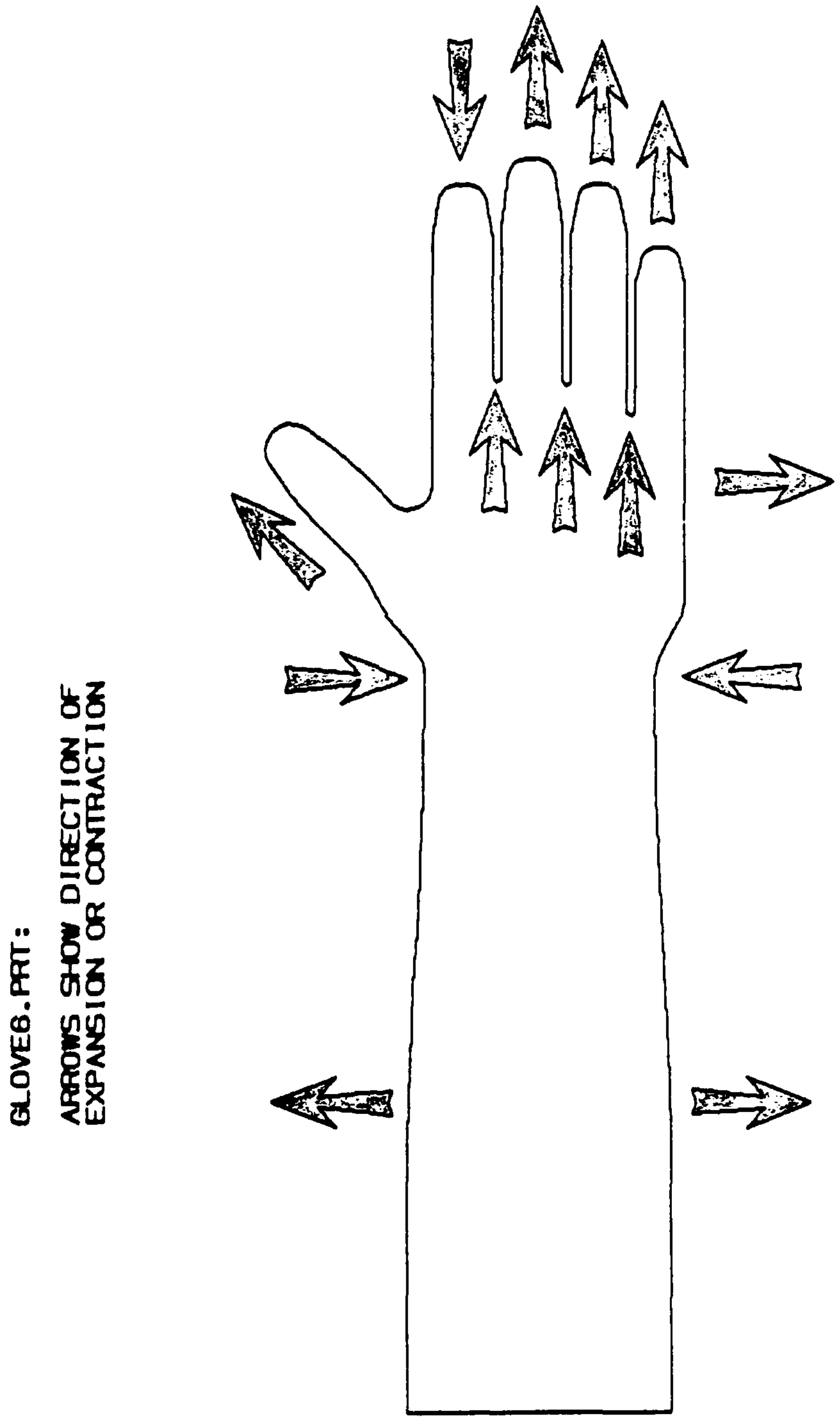

Figure 10: Deviation from the Design

APPENDIX A

The SLA system uses a laser-curable resin which is post-cured in a bath of ultra-violet light. The material exists in three distinct phases-- liquid resin, laser-cured resin, and ultra-violet post-cured resin.

Resin	Properties
Liquid Resin	
Appearance	Transparent liquid
Density	1.14 g cm^{-3}
Viscosity, Brookfield	1600-2400 cps @ 25°C
	950-1350 cps @ 35°C
Laser-Cured Resin	
Tensile Strength	5-10 N mm^{-2}
Tensile Modulus	80-100 N mm^{-2}
Elongation	5-10%

(Samples prepared according to ASTM 638M, DIN 52455, ISO R527.)

Ultra-Violet Post-Cured Resin	
Tensile Strength	50-70 N mm^{-2}
Tensile Modulus	2500-3500 N mm^{-2}
Elongation	2-3%

Chemical Identity of Resin	% by Mass
Acrylate ester of bisphenol A-epoxy resin	50
Ethoxylated bisphenol A dimeth-acrylate	20
Trimethylolpropane triacrylate	10
1-Hydroxycylcohexyl phenyl ketone	10
1-Vinyl-2-pyrrolidinone	10

The manufacturer includes health and safety warnings for use with the uncured resin. The cured resin is safe.

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4. AUTHORS (Last name, first name, middle initial)
HIDSON, David

5. DATE OF PUBLICATION (month and year of publication of document)
JUNE 1992

6a. NO. OF PAGES (total containing information. Include Annexes, Appendices, etc.)
21

6b. NO. OF REFS (total cited in document)
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7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)
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9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant)
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10a. ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.)
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